Comparison of Beta-Carotene Content of Dried Carrots Prepared by Three Dehydration Processes

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SUMMARY

β-carotene was compared in fresh carrots, and carrots dehydrated by explosive puffing, air drying, and vacuum freeze-drying. Total β-carotene content of the explosive puffed product compared quite favorably with that of the vacuum freeze-dried product, both before and after cooking. The conventional air-dried product had a lower total β-carotene content. The *trans* isomer of β-carotene (provitamin A) was also compared. Of the *trans* isomer available in the blanched fresh carrot, approximately 60% was retained by both the explosive puffed and conventional dried products, while about 80% was retained by the freeze-dried products. After proper reconstitution, however, the retention of *trans* β-carotene was 76% for freeze-dried carrots, 64% for explosive puffed, and 52% for conventional dried carrots.

INTRODUCTION

In the evaluation of a dehydrated food product many factors important to the consumer must be considered, such as appearance, taste, texture, and convenience of preparation. Of equal importance is the nutritional quality of the product.

Since carrots are an important source of vitamin A, the following study was undertaken to determine the β-carotene content of dehydrated carrots produced by the newly developed explosive puffing process (Cording *et al.*, 1963). The suggested approach of Brubacher and Vuilleumier (1963) was followed for carotene determination. They recommended establishment of a standardized method for carotene analysis applicable to all products under investigation. Although this approach does not provide absolute values, it does permit a reasonably accurate estimate of the nutritional quality of products studied on a comparative basis.

The β-carotene content of this new product was compared with that of carrots dehydrated by conventional hot-air drying and by vacuum freeze-drying. Fresh carrots were used as the basis for comparison. Freeze-dried carrots were included because freeze-drying represents the "ideal" method for heat-sensitive products susceptible to oxidation. Since carrots are generally eaten cooked rather than raw, blanched, or dehydrated, the retention of β-carotene of each of the products after cooking was also determined and compared with that of fresh cooked carrots.

Harris and Von Loesecke (1960) and Beadle and Zscheile (1942) indicated that a true assessment of the nutritional quality of dehydrated carrots depends not only on the total β-carotene content but on the degree to which this compound has isomerized. The fact that β-carotene may exist in twenty isomeric forms (Zechmeister, 1944), each of which possesses varying provitamin A activity, indicates the magnitude of this problem. It is generally accepted that the *trans* isomer is the only form possessing 100% provitamin A activity (Bickoff and Thompson, 1949). Although determining the amount of *trans* isomer alone will not permit a complete evaluation of the vitamin A potential of the products studied, it will be a more reliable index than solely a total β-carotene value with no knowledge of its isomeric composition. Therefore the amount of *trans* isomer was also determined along with total β-carotene.

MATERIALS AND METHODS

Preparation of samples. The carrots used were the Red Core Chantenay variety. Five lots were purchased commercially, and the three types of dehydrated products were prepared from each lot. They were prepared for processing by lye peeling for 2½ min at 150°F. Before mechanical dicing to ⅜ in. the carrots were trimmed and then dipped in a sodium bisulfite-citric acid solution (0.5% each) for ½ min. They were then diced and sized over a 3/16-in. slotted screen. After steam blanching for 6 min the carrots were divided and dried by the three processes.

Conventional air drying. Dehydration was carried out by placing carrot dice in a through-circulation dryer with air at 200°F until moisture content was reduced to approximately 35%. Air temperature was then lowered to 150°F for final drying to about 3–4% moisture. Total drying time was about 8 hr.

Explosive-puffed drying. In this process the initial drying was identical to the first stage of the air-drying process described above. When the product attained a moisture level between 35 and 40%, however, it was removed from the dryer and placed in an explosive puffer and exploded at 35 psig (Cording *et al.*, 1963). These pieces were then dried to 3–4% moisture with air at 150°F. Because of the porous nature of the explosive puffed piece, considerably less drying was required than for conventional pieces, i.e., a total of 5½ hr instead of 8 hr.

Vacuum freeze-dried carrots. A single layer of blanched dice was frozen in trays having a 4-mesh screen bottom. Frozen dice were dried in a Stokes vacuum dryer (no endorsement implied) at an absolute pressure of approximately 1000 μ Hg. Product temperature was maintained below 160°F throughout the drying period. These conditions permitted drying in about 4–5 hr. The dryer was vented with nitrogen gas.

Products obtained by all three processes were immediately canned under nitrogen and stored in a freezer at 0°F until analyzed.

ANALYTICAL PROCEDURE

Extraction of carotenes. Fresh carrots were extracted as described by Wall and Kelley (1943) but with the following modifications:

Carrots were ground through a food chopper to ensure a well mixed repre-

sentative sample. Extraction and all subsequent steps were carried out in a semi-dark room to minimize isomerization due to light. Samples were initially extracted with 150 ml 95% ethyl alcohol for 5 min in a Waring blender, after which 75 ml skellysolve B (boiling 63–70°C) were added. Extraction was continued for an additional 15 min, after which the mixture was filtered through a coarse sintered-glass funnel. The skellysolve B–alcohol extract was washed with 100 ml 1% Na_2SO_4 instead of the 5% solution as recommended. Extraction then proceeded as they described.

Reflux extraction (Wall and Kelley, 1943) of dehydrated carrots was found to be inadequate for complete removal of the total carotenoids. Booth (1945) found that wetting dried plant material greatly improved the extractability of carotenoids. Therefore, an alternate method was adopted. Carrots were first ground through 40-mesh screen, weighed (500 mg), and soaked for 5–10 min in about 20 ml H_2O, then filtered through filter paper under slight vacuum to remove excess H_2O and transferred to a blender with 95% ethyl alcohol. Extraction then continued as for fresh carrots. This method assures the complete removal of total pigments from carrots.

Cooked samples were extracted in the same manner as fresh carrots. Reconstitution of the three dehydrated products was as follows: both the freeze-dried and explosive-puffed-dried products required 5–6 min of boiling, while 30–45 min was required for the air-dried product.

Separation of carotenes. The combined skellysolve solution containing the total carotenoids was concentrated by evaporation under vacuum with the temperature held below 30°C. The extracted carotenoids (400–500 μg β-carotene) were separated chromatographically on a magnesium oxide-Hyflo Super-Cel column (1:1 weight basis). Complete removal of the alpha-carotene was effected by elution with 1% acetone in skellysolve B. Following this the total β-carotene fraction was eluted with a 4% acetone-skellysolve B mixture. This fraction was concentrated by evaporating the solvent under vacuum and redissolving to a known volume with skellysolve B. Concentration of total β-carotene was determined spectrophotometrically with a portion of this solution. The remainder was used for chromatographic separation of the β-carotene isomers. A Hitachi-Perkin Elmer UV-visible spectrophotometer, Model 139, was employed for all color measurements, using a standard value of $E^{1\%}_{1cm} = 2500$ at a wavelength of 450 mμ.

Table 1. Total and all *trans* β-carotene of carrots.

Sample	Before cooking: Range of concentration[a]	Before cooking: Av. %	Before cooking: % present as all *trans* β-carotene	Before cooking: % of original amount of all *trans* β-carotene	After cooking: Range of concentration[a]	After cooking: Av. %[c]	After cooking: % present as all *trans* β-carotene	After cooking: % of original amount of all *trans* β-carotene
Fresh	622–1000	100	100	100	980–1860[d]	100	72	100
Blanched	775–1050	108	95	100	.....	.....	.....	100
Explosive puff-dried	500–900	81[b]	72	60	805–1060	60	77	64
Vacuum freeze-dried	526–890	85[b]	89	80	870–1125	65	84	76
Conventional air-dried	600–830	74[b]	80	60	636–987	49	77	52

[a] Micrograms β-carotene per g solids (MFB) [range for 5 lots].
[b] Percent based on β-carotene of blanched fresh carrots.
[c] Percent based on β-carotene of cooked fresh carrots.
[d] Represents an increase in β-carotene of 57–85% above original concentration.

Separation of isomers. The method as described by Bickoff *et al.* (1948) was employed for the separation of the *trans* β-carotene from its *cis* isomers.

The preparation of the chromatographic column was modified slightly in order to exclude trapped air and to avoid channel formation. Calcium hydroxide was suspended in skellysolve B, and occluded air was removed with slow stirring. The suspension was then poured into the column, and very slight vacuum was applied to remove solvent. When the solvent level was about 1 cm above the calcium hydroxide column, 10 ml of diluted eluting solvent (0.75% p-methyl anisole in skellysolve B) was added (Osadca, 1963). Finally, the previously concentrated β-carotene was added to the column with a small amount of skellysolve B. The chromatogram was developed with 1.5% solution of p-methyl anisole in skellysolve B. Complete absorption curves were obtained for both total β-carotene and *trans* isomer.

RESULTS AND DISCUSSION

Total β-carotene. The β-carotene content of fresh carrots was found to vary from 622 to 1000 μg/g dry solids (Table 1). Steam blanching of these same carrots produced an apparent increase in β-carotene content varying from 2 to 25% above the original values. In both cases, the carrot pieces appeared to be completely extracted. Similar increases in β-carotene of carrots and other plants after blanching have been reported by Weier and Stocking (1946), Harris and Von Loesecke (1960), and Silker *et al.* (1944). Also observed (Table 1) was a marked increase in β-carotene content of cooked carrots. This increase ranged from 57 to 85% above β-carotene content of the original fresh carrots. Absorption curves of the β-carotene extracted from both fresh and cooked carrots are identical with that of authentic β-carotene. Booth (1945) reported that others have had similar experience with cooked vegetables. Also, Bailey and Dutton (1945) observed a similar increase in β-carotene and attributed it to the loss of soluble solids during washing and blanching. The soluble solids lost during reconstitution (cooking) of three dehydrated products were determined, and the β-carotene values were corrected accordingly. Fifty to 66% of the observed increase in β-carotene was thus accounted for, indicating that losses of soluble solids are the most probable explanation for this increase.

The relatively high level of retention and close similarity (Table 1) of β-carotene content of the dried products were somewhat surprising, especially when one considers the known instability of β-carotene to oxidation. However, Heftmann (1947) found that β-carotene in carrots is remarkably stable to oxidation and quite unaffected by air drying; this was attributed to the relatively high tocopherol content (approximately 0.5%) which is naturally present and undoubtedly functions as an antioxidant. Add to this the stabilizing effect of blanching (Harris and Von Loesecke, 1960) and it is understandable why the concentration of β-carotene in dehydrated carrots is so high. Absorption curves for the total β-carotene extracted from the three types of dehydrated carrots were also found to be identical with that of authentic β-carotene.

Degree of isomerization. A correct

assessment of nutritional quality of β-carotene depends on determining the degree of isomerization of this compound. Only the *trans* form of β-carotene possesses 100% provitamin A activity, while the major *cis* forms, namely neo-β-carotene B and neo-β-carotene U, have respective activities of 53 and 25–38% (Bickoff and Thompson, 1949). Thus, limiting the discussion to total β-carotene could only lead to erroneous conclusions. Absorption curves of total β-carotene from the three dehydrated products show a peak at a wave length of 340 mμ. This signifies the presence of *cis* isomers, which, since this peak is absent in the extract of fresh carrot, indicates the occurrence of isomerization during processing. Therefore, it was considered advisable to determine also the concentration of the *trans* isomer, thereby gaining a better insight on the potential nutritional quality of the products under study. This was accomplished by chromatographic separation of the β-carotene isomers. After removal of the fast-moving minor components, the major band was eluted and examined spectrophotometrically. The absorption curve of the eluate showed no peak at 340 mμ, thus indicating the *trans* configuration. The percentage of β-carotene present in the *trans* form is shown in Table 1. Blanched fresh carrot, used as the basis for comparison, shows very little isomerization. The concentration of *trans* isomer found in explosive-puffed carrots after drying was identical to that in the conventional air-dried products even though there appeared to be somewhat greater isomerization with the former product due to processing. As would be expected, the freeze-dried product showed a relatively small amount of isomerization.

Table 1 also illustrates the proportion of the all *trans* isomer remaining after each of the treatments, compared with that in fresh blanched carrot. The explosive-puffed and conventional air-dried carrots still possess over 60% of the potential *trans* β-carotene available in the blanched fresh carrot. The freeze-dried product possesses about 80% of the original *trans* β-carotene.

Effect of cooking. Since carrots are generally eaten after cooking [rather than raw, blanched, or dehydrated], a comparison was made of the β-carotene and *trans* isomer contents of the four products after each had been prepared for eating. The fresh carrots (after 6 min of blanching) required 6 min of additional cooking. The time required to cook the dehydrated products varies considerably, e.g., both explosive-puffed and freeze-dried pieces require only 5–6 min boiling, while conventional air-dried carrots require 30–45 min. This difference would be expected to affect retention of total β-carotene and degree of isomerization markedly.

As indicated earlier with fresh carrots, the cooking process enhances the extraction of β-carotene, yielding a higher absolute value. Therefore, a correct assessment of the cooking effect would have to take this factor into consideration. As can be seen in Table 1, the range of concentration of each sample analyzed was greater after cooking than before.

Thus, while the dehydrated carrots before cooking were compared to the blanched fresh carrots, the dehydrated carrots after cooking were compared to fresh cooked carrots. This procedure yields a truer picture of the processing effect, including pretreatment.

It was found (Table 1) that total β-carotene in carrots prepared either by explosive-puffing or freeze-drying was nearly the same after cooking, i.e., 60% of that found in fresh cooked carrots in the former, and 65% in the latter. Only 49% was retained by the cooked conventionally dried pieces. Table 1 also shows that cooking fresh carrots caused a considerable decrease in the amount of *trans* isomers of β-carotene, while cooking the dehydrated products caused less change in this respect.

Because conventional air-dried carrots after cooking contain less total β-carotene, it will also contain less of the *trans* isomer. The amount of *trans* isomer (Table 1) still retained by cooked explosive-puffed and freeze-dried carrots was respectively about 64% and 76%, of that of fresh cooked carrot. The conventional air-dried product, which requires greater cooking time, retained only 52%.

CONCLUSIONS

Results show little difference in the total β-carotene content of the three products after processing. The *trans* isomer concentration for the explosive-puffed and conventionally dried products was found to be nearly the same, with the freeze-dried product being somewhat superior.

However, after cooking, the explosive puffed-product was superior to its conventionally dried counterpart in retention of both total β-carotene and the *trans* isomer, provitamin A. As might be expected, the cooked freeze-dried product retained somewhat higher levels.

Blanching and cooking produce an apparent increase in carotene content which is probably due to a loss of soluble solids without an accompanying loss of β-carotene. Cooking of the fresh carrot causes considerable isomerization, as was evidenced by the appearance of a *cis* peak in the absorption curve. Cooking the dehydrated products resulted in little change in the degree of isomerization. The heat treatment inherent in the drying processes may account for this.

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